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A GUIDE for DESIGN AND LAYOUT of VEGETATIVE WAVE PROTECTION for EARTH DAM EMBANKMENTS

TECHNICAL RELEASE
NUMBER 56

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Introduction

This Technical Release is the result of a joint effort by the Plant Sciences Division and the Engineering Division of the Soil Conservation Service. A committee composed of engineers, agronomists, plant materials specialists, and soil scientists studied the problem in the field and in conference and present this Technical Release as their best judgment at the present time.

This Technical Release deviates in content from former ones because of the desire of the committee to present the basic elements of their observations and discussions as a background for the judgments that were prerequisite to the procedures that follow. As the procedures presented are tried and tested by experience it is to be expected that their range of applicability would change.

General Conclusions

1. There are at least two ways to provide wave protection; (a) by providing direct protection to the embankment by a covering which will dissipate the energy of the wave at, or essentially at the cover material, such as riprap, soil cement, or some other erosion resistant material, and (b) the dissipation of the energy in the wave before it strikes the embankment by forcing it to pass through a succession of barriers. Vegetation of the right character fits into this second category. There is ample evidence that vegetation of adequate height, density, and width normal to the direction of the wave front and at the right elevation will effectively dissipate wave energy and thus protect the bank from waves of limited height.

2. Vegetative protection must be combined with a berm on the earthfill to be effective. A schematic layout of a berm is shown in cross-sectión in Fig. 2. The dimensions are noted as variables because they probably should be different for different conditions of climate, exposure, etc.

3. Vegetative protection will not work well where the water surface in the reservoir drops very far below normal pool elevation for extended periods of time. The amount of fluctuation, if not too large or too prolonged, may be accomodated by a variety of grass species of different water tolerance planted in zones on the berm.

4. The vegetation provided for wave protection must be given positive protection by the total exclusion of livestock from the area.

5. Shrubs, seldom provide the best type of vegetation for wave protection, because; (a) they take too long to establish the density of vegetation necessary to control the wave action, (b) such plantings tend to induce intrusion of larger trees, such as black willow and cottonwood, which, unless cut and kept out of the stand, will grow large and shade out the effective plants, and (c) an effective planting of willows appears to be difficult to maintain.

6. Most of the wave erosion observed seemed to start at the water level in the reservoir from relatively small waves, probably not more than a foot in height which appeared to create a progressively larger vertical face on the embankment by undercutting, sloughing, and washing away of the embankment material. Grasses that have commonly been used are often unable to provide adequate protection against the prolonged impact of small waves against the bank.

7. Very little damage was evident on the embankment slopes above the nearly vertical banks formed by the process outlined in item 6 above eventhough there was some evidence and considerable testimony that the water surface had been at these higher elevations on some of the dams. Apparently, the <u>duration</u> and <u>frequency</u> of the wave attack at any particular elevation has a considerable effect on the amount of erosion produced.

8. Testimony indicated that on at least some of the dams with considerable wave erosion damage, most of it developed in one storm or two and in some cases dams which had existed without significant damage for several years were severely damaged in one storm.

9. Apparently, the wind can blow in any direction with enough velocity to effect erosion on the face of a dam. Our observations could not detect any relationship between the direction of prevailing wind, and the severity or frequency of damage from waves. A careful statistical study of these factors might demonstrate a relationship but it is doubtful that any structure in the areas we observed could be considered as protected from wave damage because it faced a particular direction.

10. There seems to be some correlation between the exposure, i.e. the elevation of the reservoir water surface relative to the general elevation of the land surrounding the water and the extent of timber on the surrounding land, and the degree of wave erosion on the earth dam embankment. The amount of wave erosion seems to decrease as the difference in elevation increases.

11. The erodibility of the soils in the embankment is a variable in the relationship between the attack of the waves, as measured by the height and duration of the waves, and the extent or severity of the wave erosion produced. It is extremely difficult to isolate this variable as it is also for the others that measure the attack or the resistance of the embankment vegetation. Dispersible clays would be especially vulnerable as would fine grained soils of low or no cohesion. With an increase in cohesion there should be an increase in resistance to wave erosion although as pointed out earlier it was difficult to isolate this variable by visual observation. Probably the most important characteristic of the soils involved is their ability to support vigorous vegetation.

12. Of all the variables affecting the problem, the relationship between attack and time is the most unpredictable. The coincidence of damaging wind velocity and direction to product attacking waves of sufficient height and energy to cause significant erosion appears to be a random event. Several of the dams observed had stood without damage for several years but when the right combination of variables prevailed serious erosion resulted. This would make it reasonable to expect that other similar dams, undamaged to date, might be subjected to serious wave erosion damage in the future. Thus it would seem questionable to rely on historical studies based on other than long-term records.

13. A team effort is absolutely necessary to the investigations, design, and installation of vegetative wave protection. Geologists, soil scientists, agronomists, plant materials specialists, hydrologists, and design engineers must work together to properly evaluate the applicability of vegetative wave protection to each particular site, to evaluate the geologic and soil materials available for wave protection, to determine the soil treatments that may be necessary to provide for long time growth and vigor of the plants selected, to select the plants that will be most effective over a long period of time, to layout a berm of the correct size, slope, and elevation, and to determine the position of the various recommended species of plant materials on the berm to attain the desired level of wave protection. The various technical skills of those involved must be brought to bear on each problem at the proper time. The decisions that must be made are highly interdependent and late input by any of the team can only produce inefficiency and confusion.

Applicability of Vegetative Wave Protection

Vegetative wave protection is applicable:

1. On earth dams where the accumulative volume of inflow to the reservoir remaining, after seepage and evaporation losses is sufficient to maintain the normal pool level within the vertical fluctuation range of a gently sloping berm.

Vegetation for wave erosion control is not applicable on municipal, industrial, irrigation, or other dams subject to fluctuating water surfaces resulting from variable beneficial uses.

Use of water tolerant and aquatic vegetation as a wave barrier on the upstream berm of a dam, imposes the design requirement that deviation of the water surface from the design elevation must be of short duration and within tolerable limits to sustain the selected plants.

In considering selection of a vegetated wave barrier, all factors contributing to lowering of the permanent pool for any reason including those that are inherent to the physical and climatic character of the site, must be evaluated.

2. Where suitable soil depth, texture, and fertility are or can be made available for timely and complete vegetative establishment in a period of not more than two growing seasons and to thereafter continuously sustain vigorous vegetative growth under normal rainfall, proper operations management and maintenance, including irrigation and fertilization as needed, during establishment or prolonged drought periods.

3. On sites where there are insufficient quantities of usable quality rock, sand, or gravel materials available from required construction excavations for use as riprap, bedding, or sand-gravel slope protection. Where there are sufficient quantities of these materials available they should be used, in lieu of vegetative protection, for riprap or sand-gravel slope protection if it is economical to do so.

4. Only where the responsible local sponsors and/or individual owners and operators have entered into a binding, written operation and maintenance agreement with the Soil Conservation Service to properly operate, manage, and maintain the total structure. The operations, management, and maintenance agreement provisions should include regulation of reservoir water surface elevation and irrigation during establishment, fertilization and re-establishment of vegetation as needed, fire prevention, exclusion of grazing by domestic animals, prevention of fishing and boating from the dam, control of rodents, cutting and killing of tree species that could grow tall and kill out the desirable wave protection grasses or shrubs.

Wind Velocity, Fetch, and Wave Height

The energy of the wind is conveyed and applied to the embankment via the waves generated by the wind acting on the water surface. The height of the wave is a measure of the energy contained in each wave and of the energy that must be dissipated by the vegetation from each successive wave.

A technical paper entitled "Freeboard Allowances for Waves in Inland Reservoirs" by Messrs. Thorndike Saville, Jr., Elmo W. McClendon, and Albert L. Cochran published in the Journal of the Waterways and Harbors Division of the Proceedings of the American Society of Civil Engineers, May 1962, provides the following dimensionless equation which relates wave height to wind velocity and effective fetch.

$$\frac{gH}{V^2} = 0.0026 \left[\frac{gF}{V^2}\right]^{0.47} \tag{1}$$

where g = the accelleration of gravity in ft. per second^2.

H = wave height in feet.

V = integrated wind velocity in feet per second.

F = the effective fetch length in feet.

Conversion of the velocity units in equation (1) to miles per hour and assuming g is a constant equal to 32.16 feet per second ^{2}, produces the following equation:

$$H = 6.20 \times 10^{-4} V^{1.06} F^{0.47} \tag{2}$$

in which the units are the same as in equation (1) except for V which is now expressed in miles per hour.

Available evidence indicates that wind velocities seldom exceed 50 miles per hour. The committee believes that the risk of damage is acceptable from wind velocities in excess of 50 miles per hour on earth dams, where vegetative protection against wave action is otherwise feasible. It also believes, that although the probability of a 50 mile per hour wind probably varies with the direction of the wind at a given location, that such a wind would occur from any direction. Substitution of V = 50 miles per hour into equation (2) produces:

$$H = 3.92 \times 10^{-2} F^{0.47} \tag{3}$$

A well established stand of recommended vegetation with a width of 20 feet or more in the direction of the attacking waves could dissipate the energy in a wave having a height of approximately 1.5 feet. Such treatment on a berm of proper layout will provide protection against waves generated by a 50 mile per hour wind on an effective fetch of about 2,330 feet in length. The infrequency of wind in excess of 50 mph velocity is such that maintenance is more economical than providing the original investment that would be required to avoid it. The sponsors should be formally advised and fully aware of this risk.

Messrs. Saville, McClendon and Cochran found that the "width of a fetch in reservoirs normally places a definite restriction on the length of the effective fetch; the less the width-to-length ratio, the shorter the effective fetch." They devised the following procedure for computing effective fetch and found that it "appeared to give reasonable and comparable results for the many and varied fetches of the Fort Peck and Denison wave stations," when used in conjunction with equation (1).

Computation of the maximum effective fetch for a dam is essentially a trial and error process. For each trial the procedure can be described by the following step by step process:

1. From a selected point on the upstream face of the dam lay out 15 radial lines which are 6 degrees apart. The center line represents the chosen wind direction, and the zero (0) angle with the wind direction, selected for this trial. Each radial line should be extended to an intersection with the reservoir contour that represents the elevation of the water surface in the reservoir for the fetch being calculated.

2. From the intersection of each of the 6, 12, 18, 24, 30, 36 and 42 degree lines with the shore line, draw perpendiculars to the zero degree line.

3. Measure the length of the projection of each line ($\chi\alpha$) on the zero degree line and record them in a table such as shown in the following example.

4. Multiply the tabulated values of χ_α by Cos α and tabulate

5. Add the fifteen items in the column headed $\chi\alpha$ Cos α to produce $\Sigma\chi\alpha \cos \alpha$

6. Calculate the effective fetch

$$F_e = \frac{\Sigma\chi\alpha \text{ Cos } \alpha}{\Sigma \text{ Cos } \alpha} = \frac{\Sigma\chi\alpha \text{ Cos } \alpha}{13.512}$$

To perform the trials for any specific site it is necessary to have a topographic map of the reservoir from which a water surface contour line map can be made. The above procedure is illustrated by the following example No. 1 which is summarized in Fig. 1A, B and C, and Table 1.

Given - A water surface contour map

Step 1. Layout line A (the direction of the wind) and the other 14 lines at six degree intervals as shown in Fig. 1A; extend these lines to an intersection with the water surface contour.

Step 2. Draw perpendiculars to the zero degree line through each of the 14 intersections in step 1.

Step 3. Measure the length of the projections of each line on the zero degree line and record them in a table, Trial A., $\chi\alpha$

Step 4. Multiply $\chi\alpha$ by Cos α and record the product in a table, Trial A, $\chi\alpha$ Cos α

Step 5. Compute $\Sigma\chi\alpha$ cos α, Trial A

Step 6. Calculate F_e

Repeat the process for Trials B and C. Make sufficient trials to find a value of F_e near the maximum for wind from any direction. In this example, Trial B gives a value F_e = 2258 ft. which is near the maximum for any wind direction.

From equation (3), which is for a wind velocity of 50 miles per hour, with an effective fetch of 2258. feet the estimated wave height is -

$$H = 3.92 \times 10^{-2} (2258)^{0.47} = 1.48 \text{ ft.}$$

TABLE 1

Example 1 - Computation of Effective Fetch

α	Cosα	Trial A		Trial B		Trial C	
		$\chi\alpha$	$\chi\alpha$Cosα	$\chi\alpha$	$\chi\alpha$ Cosα	$\chi\alpha$	$\chi\alpha$ Cos α
42	0.743	850	632	870	646	720	535
36	0.809	890	720	1580	1278	1810	1464
30	0.866	980	849	1850	1602	2880	2494
24	0.914	1070	978	2470	2258	3500	3199
18	0.951	1860	1769	3590	3414	2710	2577
12	0.978	2210	2161	3540	3462	2330	2279
6	0.995	3210	3194	2570	2557	2210	2199
0	1.000	3860	3860	2170	2170	2380	2380
6	0.995	3570	3552	2170	2159	3060	3045
12	0.978	2450	2396	2380	2328	3130	3061
18	0.951	2050	1950	3060	2910	2500	2378
24	0.914	2010	1837	2750	2514	1500	1371
30	0.866	2150	1862	2060	1784	1260	1091
36	0.809	2690	2176	960	777	1190	963
42	0.743	2170	1612	870	646	1500	1115
Σ	13.512		29,548 ÷ 13.51 =		30,505 ÷ 13.51 =		30,151 ÷ 13.51 =
F_e			2187		2258		2231

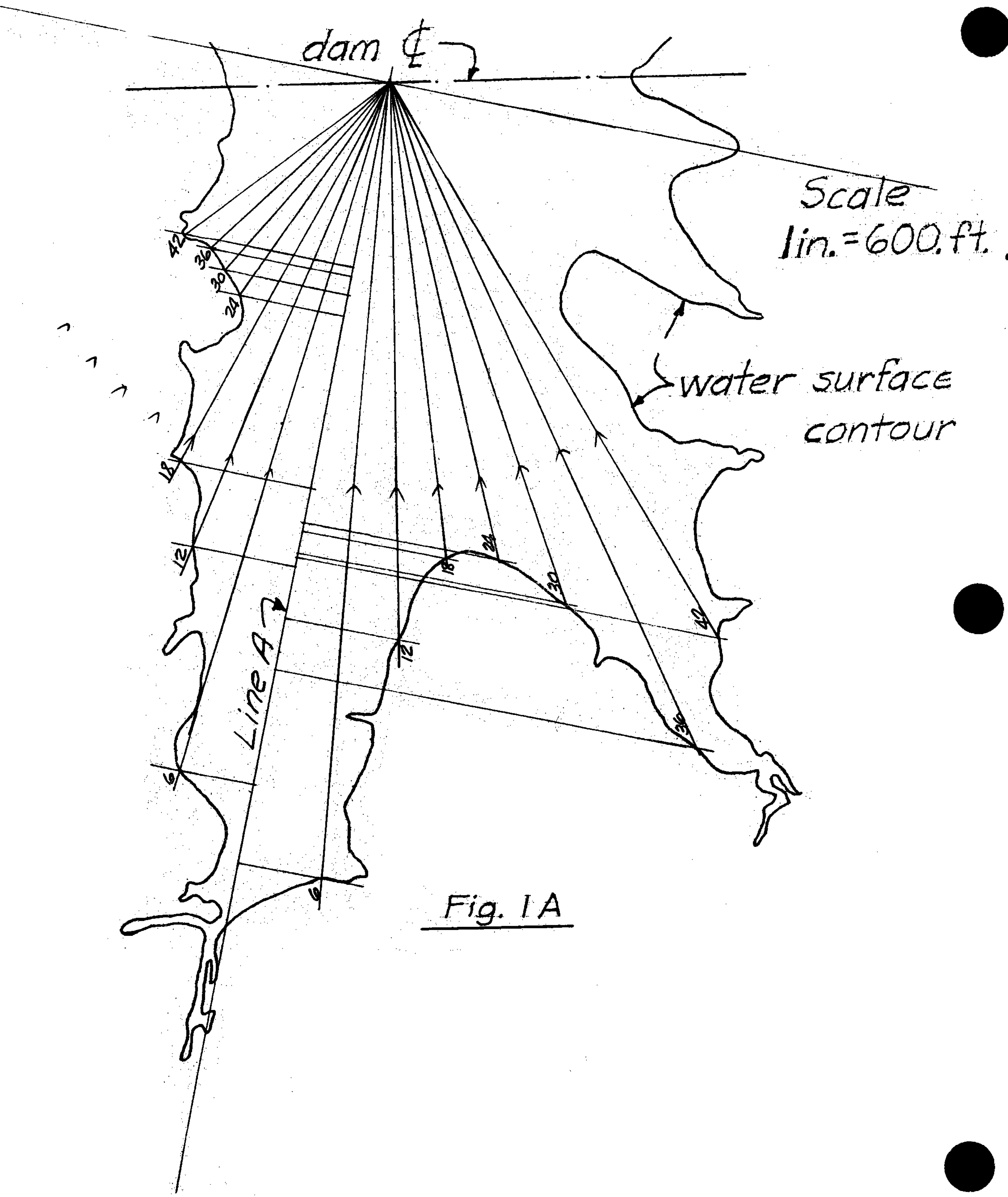

dam ℄
Scale
1in.=600.ft.
water surface
contour
Line A
42
36
30
24
18
12
6
18
24
30
42
12
36
6

Fig. 1A

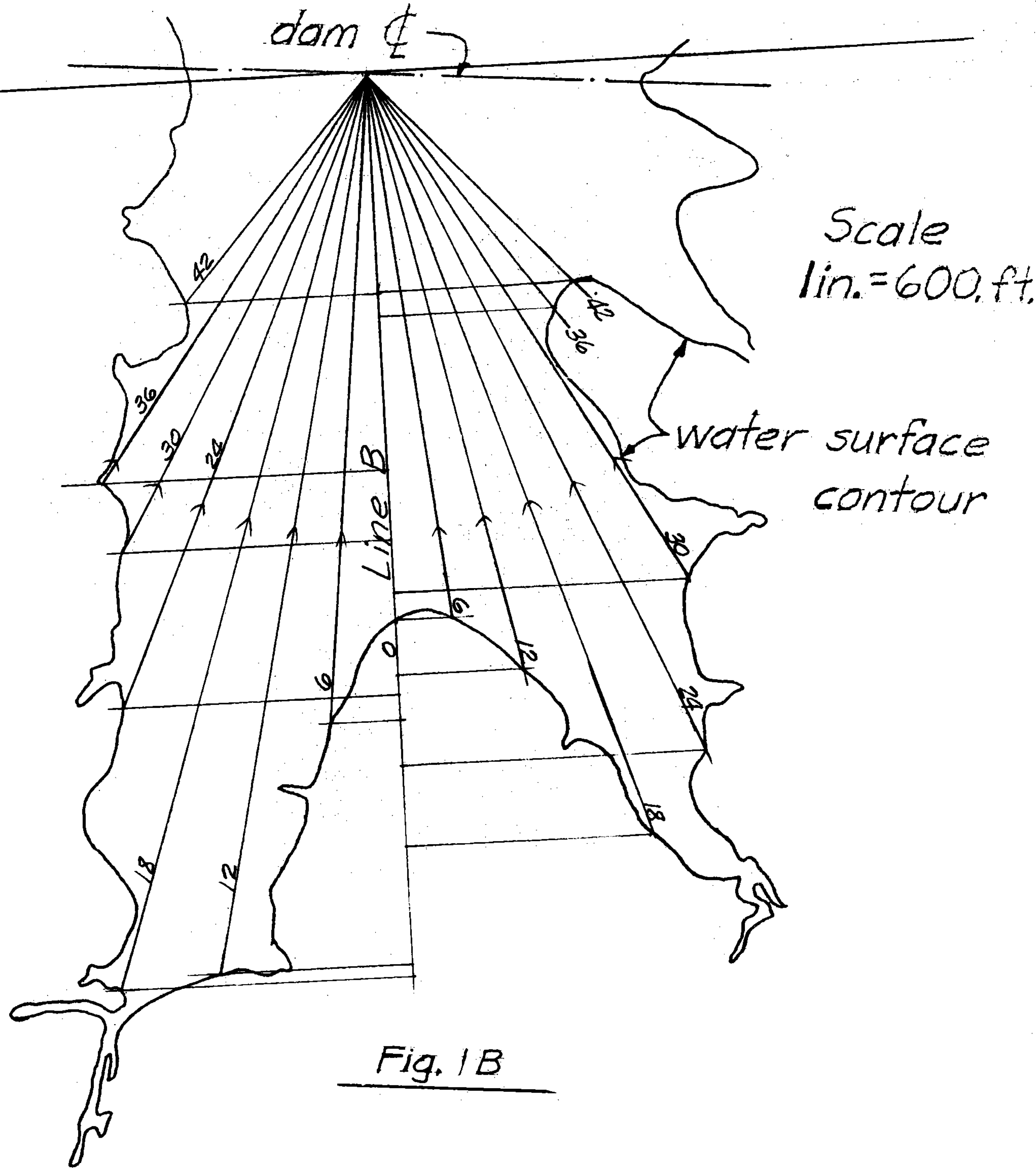

dam ℄
Scale
1in.=600.ft.
water surface
contour
Line B
42
36
30
24
18
12
6
0
42
36
30
24
18
12
6

Fig. 1B

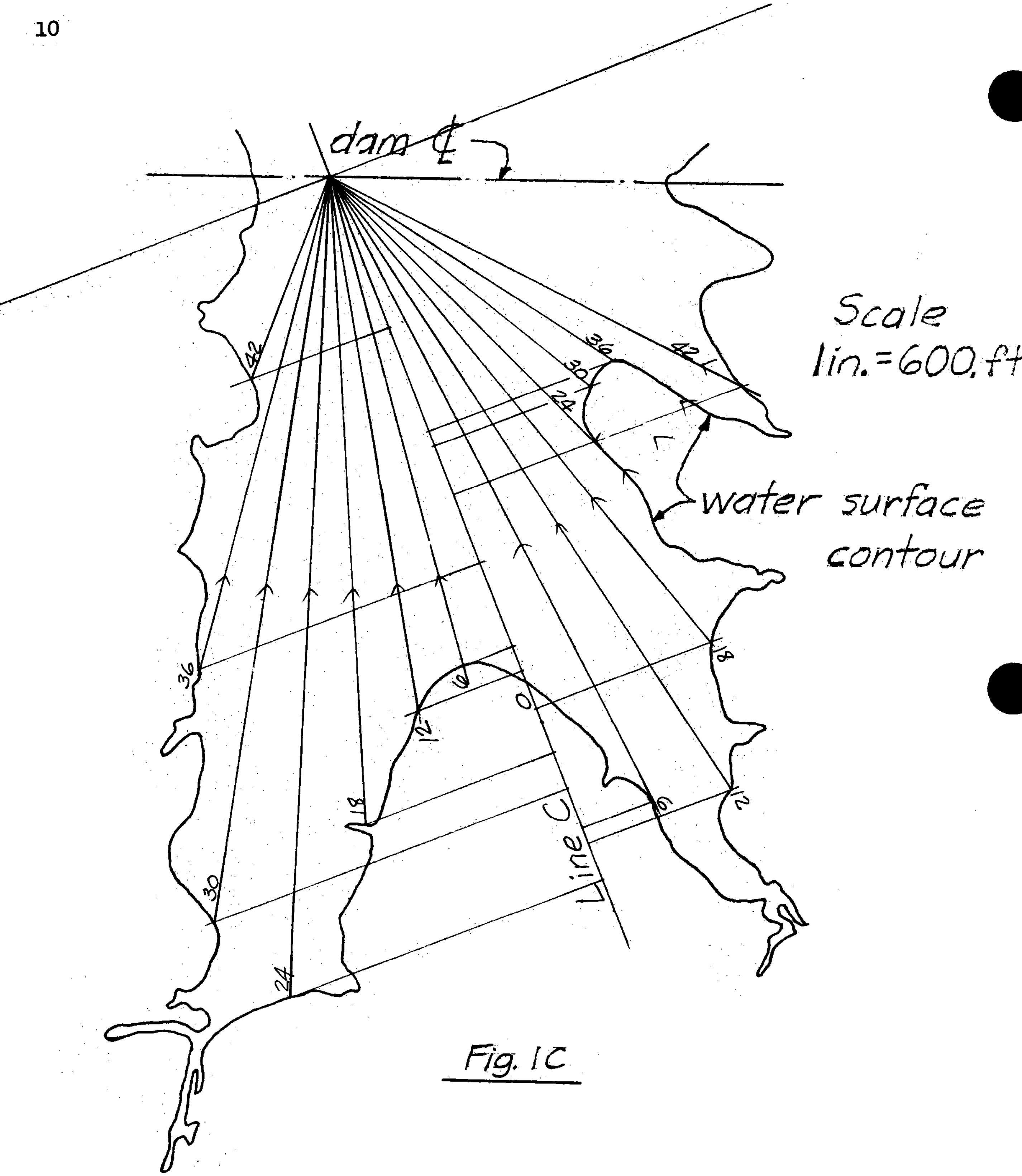
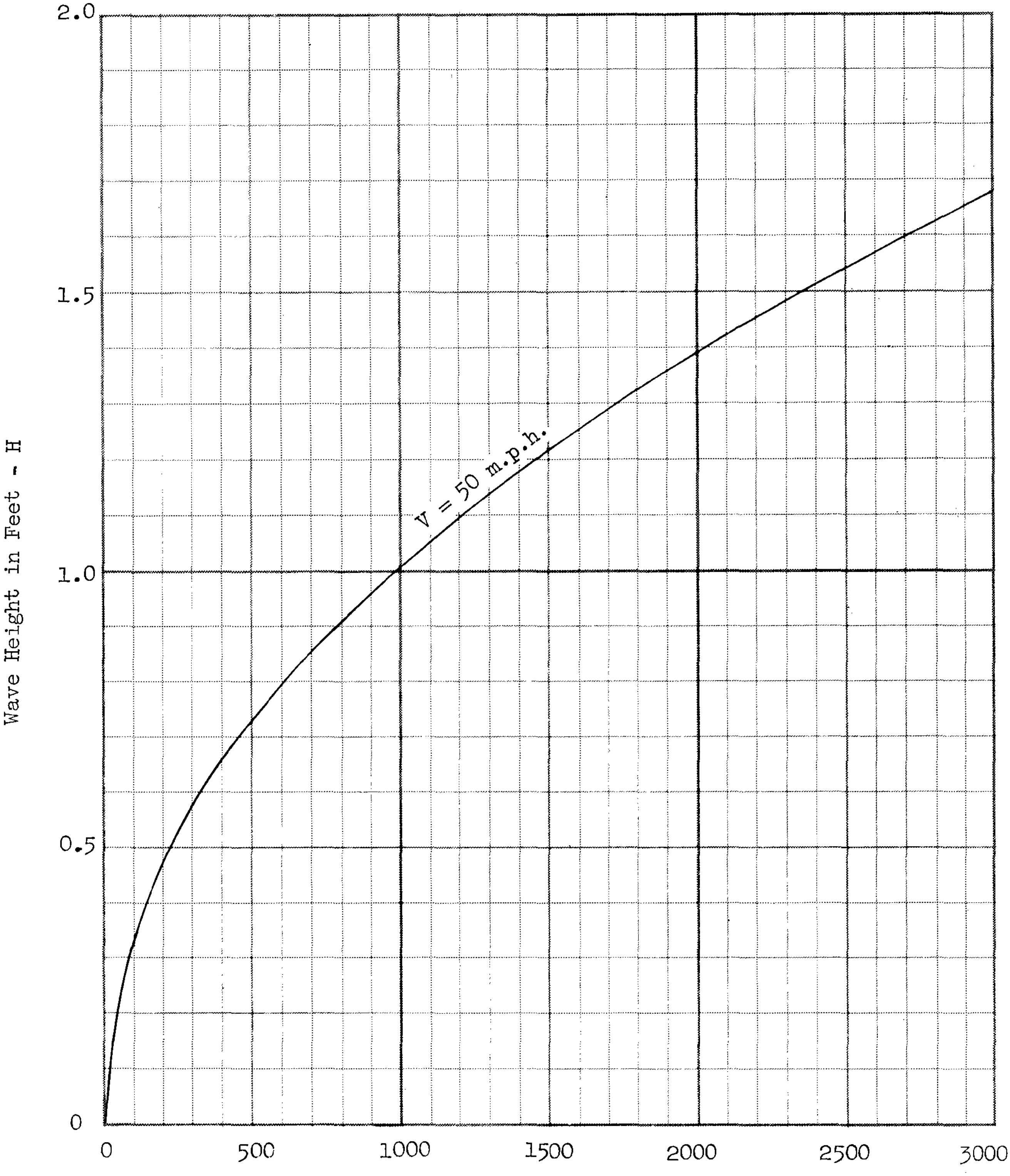

dam ℄
Scale
1in.=600.ft
water surface
contour
42
36
30
24
42
36
30
24
18
12
6
0
6
12
18
12
Line C

Fig. 1C



Effective Fetch in Feet - F_e

$$H = 3.92 \times 10^{-2} F_e^{0.47}$$

Fig. 1D

Berm Layout

The layout of the berm is very important to the success of vegetative wave protection. The recommended berm cross-section is shown in upper cross-section in Fig. 2.

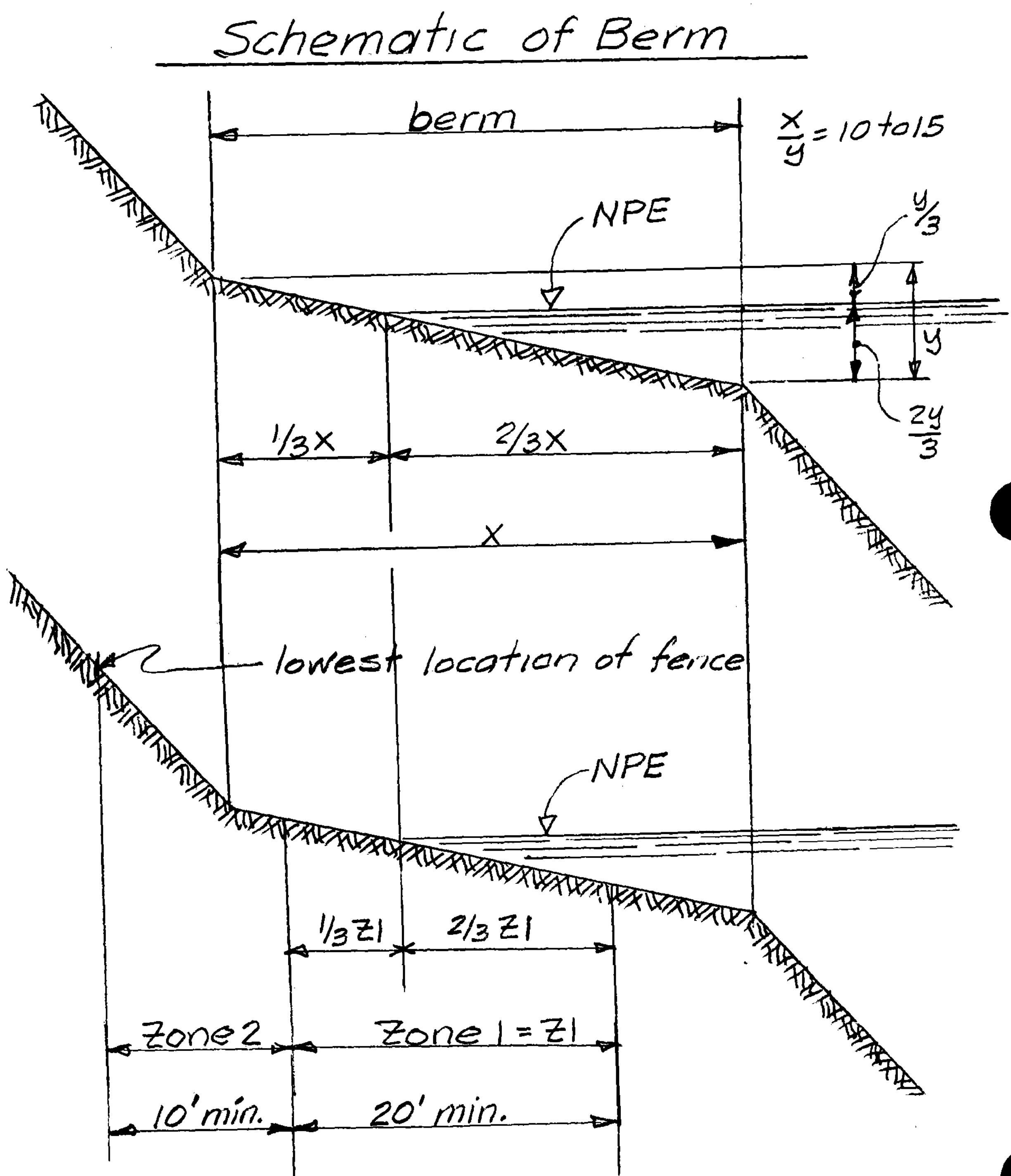


Fig. 2

The berm width, x, should be at least 20. feet. The part of x above the normal pool elevation in the reservoir, NPE, should be about one-third of x with a minimum of 6 feet. The part of x, below the NPE, should be about two-thirds of x with a minimum of 14 feet. The ratio $x \div y = z$, where y is the difference in elevation between the upstream and downstream extremities of the berm, should be a minimum of 10. For effective fetch lengths, F_e, greater than 500 feet, z should exceed 10; use values up to 15 as F_e increases.

Planting zone 1 shown in the lower cross-section of Fig. 2 should have a minimum width of 20. feet divided with about one-third above NPE and two-thirds below. Planting zone 2 should have a minimum width of 10 feet which may extend up the embankment slope. Zone 2 should be greater than 10 feet in width and extend up the embankment slope to provide protection during periods of slow drawdown of the reservoir that might result from the use of a two-stage inlet or a low capacity principal spillway on a large reservoir.

It is <u>imperative</u> that planting zones 1 and 2 be protected against grazing by a high grade durable fence.

Vegetative wave protection should not be used if the water surface can be expected to drop below the elevation of the upstream edge of the berm and remain below this elevation for more than a week or two. As discussed elsewhere, the effectiveness of vegetative wave protection depends primarily on the dissipation of energy as the wave passes through a dense growth of the protecting vegetation. If the waves strike below the area that is protected by such vegetation, the vegetation is apt to be undermined and become ineffective. A conservative approach should be followed in evaluating this possible detrimental situation.

The water surface may be temporarily lowered to an elevation below normal pool elevation for some useful purpose if the vegetation is sustained by proper irrigation for the time interval involved.

Where short term or modest drops in the water surface below the NPE are expected to occur infrequently, and it is economical to extend the berm in an upstream direction so that the elevation of the upstream edge of the berm will be lower than the water surface, this should be done. This would increase the width of the berm and should the water surface remain low, the vegetation might spread and provide protection at the lower elevation. Some of the plant species listed for zone 1 might extend their coverage in an upstream direction even though the water surface remained at NPE. This would be desirable in that protection would be provided for a greater range in flucuation of the water surface.

The normal pool elevation to be used in vegetative wave protection design is defined as the elevation of the water surface in the reservoir during the passage of the maximum base flow through the spillway with the reservoir full. Maximum base flow, as here used, means the maximum inflow into the reservoir from watershed storage not related to any specific surface runoff event.

To facilitate the design of an effective vegetative wave protection system for the earth embankment, the spillway system should be designed so that the maximum base flow does not require a reservoir stage more than four inches (0.33 feet) above the crest elevation of the lowest ungated spillway.

The normal pool elevation of the reservoir is the elevation of the water surface in the reservoir during the passage of normal perennial base flow through the spillway system, or in the absence of perennial base flow the crest elevation of the lowest ungated outlet of the spillway system.

This criteria may require an increase in the crest length of a single stage principal spillway or the use of (box inlet-orifice outlet) low stage inlet having the required weir length instead of a simple orifice for the lower stage of a two-stage principal spillway.

Selection and Establishment of Wave Protection Vegetation

Required Characteristics of Plants

Two berm zones are utilized to facilitate the proper selection of wave protection plants. They are illustrated in Figure 2. Zone 1 is the more important of the two. Plants for zone 1 should possess all of the following characteristics.

1. Adaptation to water, but with the ability to survive drought stress of short duration.

2. Adaptation to water in such a manner that they are able to produce stems as emergent aquatics, coupled with the ability to produce stems from the saturation zone through, or on, several inches of soil exposed as mesic plants.

3. Ideally they should be rhizomatous or stoloniferous, but they may be of a type that root at the nodes of lodged culms or branches, or that are self seeders.

4. Ideally they should be evergreen, but may be deciduous or die back to the ground each year if the current growth will stand through the dormant season.

5. For fetches in excess of 1500 feet, they should stand at least 5 feet and may be taller. For fetches less than 1500 feet they should be at least 2 feet and may be taller.

6. They should have heavy stems, flexible, and at least 1/4 inch in diameter at the base for tall material, and at least 1/8 inch in diameter at the base for smaller material.

7. The plants should be colony types standing at no less than 5 stems per square foot of surface area.

8. They should be of proven local adaptation.

9. They must be perennials.

Plants for zone 2 should, in general, have most of the characteristics listed for zone 1, except that:

1. They should be mesic types capable of enduring short duration inundation without serious damage.

2. They may be sodformers or bunch types provided they maintain closed stands.

3. Height is not as important in this zone as in zone 1, but taller plants are more desirable than shorter ones. They should provide complete ground cover from their tops to the base.

Selection of Plants

The best plant for a given site should be selected based on a consideration of the degree to which it meets the required characteristics, its adaptability, rapidity of establishment, and its reasonable availability. This does not mean that a plant should be used because it is readily available, over the hill, when a more desirable plant is available in the next county.

Plants should be selected from the following table. Zone 1 plants are divided into two groups depending upon their estimated ability to dissipate waves from a 50 mile per hour wind depending upon the effective fetch length. The first group, under the heading "Effective Fetch Length - 0 to 2330 Feet", should always be used if any of the plants listed are adapted and available.

The second group, under the heading "Effective Fetch Length - 0 to 500 Feet", should be used only if more desirable plants in the first group are not adapted or are unavailable. The plants in the second group are generally shorter in height and will provide protection against the waves over a smaller vertical interval of the embankment face.

Zone 2 plants (see Fig. 2) should be extended well up the embankment face if the effective fetch is greater than 500 feet or if the release rates through the principal spillway are low so as to produce longer than usual exposure of the higher elevations of the dam face to wave action under the larger storm runoffs.

The map showing "Regions of Plant Distribution" from SCS National List of Scientific Plant Names, is to be used with the table "Regions of Plant Adaptations for Wave Erosion Control" to provide a selection of adapted plants.

Planting and management guide sheets have been prepared for several key plants. The plants were selected to represent each of the four kinds of propagating plant materials used for wave erosion control, namely:

Rhizomes or Stolons	- R
Plant Stock	- P
Cuttings	- C
Corms	- K

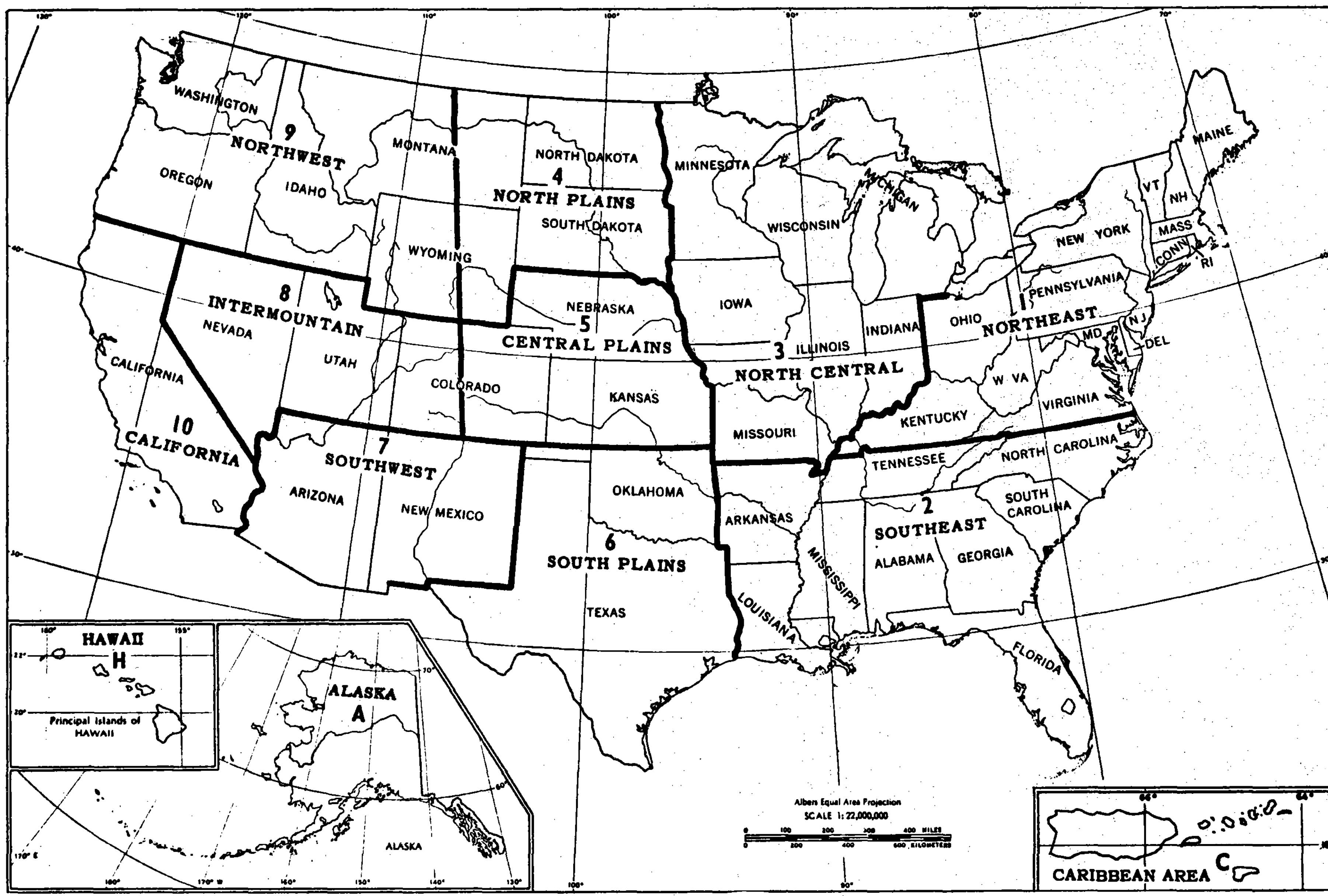
Regions of Plant Adaptations for Wave Erosion Control 1/

Zone and Effective Fetch	1	2	3	4	5	6	7	8	9	10	Source of Plant Materials: Comm.	Source of Plant Materials: Local Collection	Estab. by: Seed	Estab. by: Veg.
Zone 1 - Effective Fetch 0-2330 Feet														2/
Common reed, Phragmites communis	X	X	X	X	X	X	X	X	X	X		X		R
Maidencane, Panicum hemitomon	X	X				X						X		R
Southern wildrice, Zizaniopsis mileacea	X	X	X			X						X		P
Big cordgrass, Spartina cynosuroides	X	X			X	X						X		R, P
Sand cordgrass, Spartina bakeri		X										X		P
Smooth cordgrass, Spartina alterniflora	X	X			X	X			X			X	X	R
Planertree, Planera aquatica	X	X	X			X						X		P
Speckled alder, Alnus rugosa (acid soil, low elev.)	X	X	X	X	X	X			X			X		P
Green alder, Alnus crispa (acid soil, high elev.)	X	X	X									X		P
Switchgrass, Panicum virgatum (lowland types)	X	X	X	X	X	X	X	X			X	X	X	-
Prairie cordgrass, Spartina pectinata	X	X	X	X	X	X	X	X	X	X		X	X	R
Virginia cottonsedge, Eriophorum virginicum	X	X	X	X	X							X		P
Sandbar willow, Salix interior	X	X	X	X	X	X						X		C, P
Common cattail, Typha Latifolia	X	X	X	X	X	X	X	X	X	X	X	X	X	R, P
Zone 1 - Effective Fetch Less Than 500 Feet														
Marshhay cordgrass, Spartina patens	X	X	X		X	X						X		R, P
Torpedograss, Panicum repens		X				X						X		R
Perennial goobergrass, Amphicarpum muhlenbergianum		X										X		P
Reed canarygrass, Phalaris arundinacea	X	X	X	X	X	X	X	X	X	X	X		X	R, P
Creeping foxtail, Alopecurus arundinaceus	X		X	X	X			X	X	X	X		X	R
Fowl mannagrass, Glyceria striata	X	X	X	X	X	X	X	X	X	X		X		R, P
Bluejoint reedgrass, Calamagrostis canadensis	X	X	X	X	X		X	X	X	X		X	X	R
Zone 2 - Effective Fetch < 2330 Feet														
Maidencane, P. hemitomon	X	X				X						X		R
Marshhay cordgrass, S. patens	X	X	X		X	X						X		R, P
Torpedograss, P. repens		X				X						X		R
Switchgrass, Panicum virgatum (lowland types)	X	X	X	X	X	X	X	X			X	X	X	-
Bitter panicum, Panicum amarulum (upright form)	X	X				X						X	X	P
Giantreed, Arundo donax	X	X	X	X	X	X	X	X	X	X		X		K
Eastern gamagrass, Tripsacum dactyloides	X	X	X		X	X	X					X	X	K
Indigobush amorpha, Amorpha fruticosa	X	X	X		X	X						X	X	P
Myrtle, Myrica spp.	X	X	X			X			X	X	X	X	X	P
Swamp privet, Forestiera acuminata		X	X		X	X						X		C, P
Reed canarygrass, P. arundinacea	X	X	X	X	X	X	X	X	X	X	X		X	R, P
Prairie cordgrass, S. pectinata	X	X	X	X	X	X	X	X	X	X		X	X	R
Western wheatgrass, Agroyron smithi		X	X	X	X	X	X	X	X	X	X		X	R, P
Buffalograss, Buchloe dactyloides		X	X	X	X	X	X				X	X	X	-
Creeping foxtail, A. arundinacea	X		X	X	X			X	X	X	X		X	R
Switchcane, Arundinaria tecta	X	X	X		X	X						X		R
Asiatic bamboos (many genera)		X										X		R, P

1/ Source of Common Plant Names from:
  a. Woody plants - Little, Elbert, Jr., 1953 Checklist of Native and Naturalized Trees of U.S.; USDA Agric. Hdbk #41.
  b. Other plants - Kelsey, H. P., W. A. Dayton, 1942 Standardized Plant Names.

2/ **Kinds of propagating plant materials used in establishing vegetation. Refer to text for code designations.**

REGIONS OF PLANT DISTRIBUTION



When a selected plant does not have an individual planting and management guide sheet, refer to a guide describing a similar propagating plant material. The requirements for establishing the selected plant will, in most cases, be the same as shown on the reference guide sheet.

On-site Preparation

The berm and adjacent area to be planted will be covered with a layer of topsoil to a minimum of 1 foot and a maximum of 3 feet. The topsoil shall be of the highest quality surface soil of the site. It shall be free of brush and rocky materials that will be detrimental to the establishment of plants.

The area to be planted will be ripped to a minimum depth of 1-1/2 feet in the approximate vicinity of the row that will be used for planting of shrubs, rhizomes, or other planting stock. This should be done well in advance of the planting date to allow the soil to settle. The ripping would provide a more suitable rooting zone for the plants; a better soil, plant and water relationship; and a more erosion resistant berm between the topsoil and compact substrata. A site that has been filled with water prior to planting should be temporarily drawn down to prepare the seedbed unless vegetated materials will be hand planted directly into the full saturated soil.

Irrigation

Since the plants used for shoreline erosion control are aquatic or semi-aquatic, it is essential that adequate moisture be available for establishment. The most critical period for the success or failure of a planting is during the establishment year.

To ensure that plants will become well established, it is essential that supplemental water be applied as often as necessary. Adequate moisture at the sediment pool, shoreline, or rainfall is often not sufficient for a continuous vigorous growth of plants.

Shrubs should be individually watered at the rate of 1 gallon per plant immediately following planting and as often thereafter as necessary until they are fully established. Rhizomes and stolons and transplanted corms and herbaceous plants should be watered at the rate of 1-2 gallons per foot of row. A sprinkler system may be used for establishment of transplants and seeded plants. All water should be applied in a workman-like manner to assure that runoff does not occur.

PLANTING AND MANAGEMENT GUIDE FOR VEGETATIVE WAVE PROTECTION OF EARTH DAM EMBANKMENTS

Name of Plant

Common reed, Phragmites communis

Description

Common reed is a tall growing perennial. The stiff stems grow 10 to 12 feet tall at maturity. In temperate climates, the semi-woody stems remain standing well into the following season. New growth originates from stout rhizomes that interlace the soil to provide protection against wave erosion. In favorable growing conditions, full growth can be attained by the end of the third growing season. A dense stand of up to 20 plants per square foot from rhizomes can develop within 2-growing seasons. Showy plume-like seed heads develop in the summer. The young rhizomes and new shoots are attractive to beaver and nutria. Cattle readily eat the vegetative parts and all plantings must be protected from grazing.

Adaptation

Common reed is adapted to all plant regions (1 through 10). It is well adapted to a wide variety of soils as long as moisture and fertility are available. It is primarily used in zone 1 of the structures which meet its water requirements. It is widely adapted to climatic variations and fluctuating water levels even in the establishment period. It will tolerate some alkalinity and salinity, but is primarily a fresh water plant.

Establishment

A smooth, firm seedbed free of clods, stones, woody roots or other foreign matter should be prepared to a depth of approximately 4 inches. All live competitive vegetation should be destroyed. Planting material should consist of dormant rhizomes, approximately 12 to 18 inches containing 3 to 6 live buds. Rate of planting is 1-1/2 rhizomes per linear foot of row. Planting depth should be from 4 to 6 inches. Rows should not be wider than 40 inches apart on berm areas with a minimum of 3 rows. Loose soil should be kicked over the rhizomes in sufficient quantity to prevent drying until furrow can be filled and compacted with a tractor tire or a culti-packer to a smooth and level surface after planting and packing. If soil is not sufficiently moist, apply water at a rate of 2-gallons per foot of row following planting. Planting stock should be tied in bundles of from 50 to 100 rhizomes and protected from drying out.

Fertilizer should be applied during seedbed preparation at the rate of 50 pounds of nitrogen and 50 pounds of phosphorus (P_2O_5) per acre.

Management

Pool level should be kept down to prevent inundation during the first growing season. The area should be fenced to exclude all livestock. Herbicides may be used to control broadlead weed competition during the first year. Fertilizers should be applied during the second and third year after planting.

PLANTING AND MANAGEMENT GUIDE FOR VEGETATIVE WAVE PROTECTION OF EARTH DAM EMBANKMENTS

Name of Plant

Maidencane, *Panicum hemitomon*

Description

Maidencane is a warm season, rhizomatous deciduous grass found in fresh water marshes or wetlands in the south. Seed is sparingly produced and the chief method of reproduction is apparently by vegetative transplant.

A new variety of maidencane, designated "Halifax," was released for erosion control along shorelines and channels. It is highly rhizomatous and spreads rapidly to form dense masses of abundant stems. It is effective for controlling erosion in and adjacent to the edge of the water along channels and shorelines where the water level is fairly stable.

Adaptation

Regions of climatic adaptation are 1, 2, and 6 (Regions for adaptation for the Halifax variety have not been established outside of the western part of Region 2). It is adapted to zones 1 and 2, or on shorelines where water is present. Soils adaptation vary widely as long as it is either wet from inundation or has a water table near the surface. Withstands short dry periods after establishment or extended dry periods where roots can remain in contact with water in sands and mucks. It is a fresh water plant and does not tolerate saline water inundation.

Establishment

A smooth, firm seedbed free of clods, stones, and woody roots or other foreign matter should be prepared to approximately 4 inches deep. There should be no live competitive vegetation on the seedbed at planting time. Planting dormant rhizomes are preferred, but plantings can be made in the spring after dormancy is broken, or in summer if an adequate reliable moisture supply is available. Fertilizer should be applied at the rate of 50 pounds of nitrogen and 50 pounds of phosphorus (P_2O_5) per acre during seedbed preparation. Live rhizomes, approximately 8 to 12 inches long, should be planted at the rate of one per foot of row. They should be placed in furrows approximately 2-4 inches deep. Loose soil will be pushed or kicked over them to prevent drying until the furrow can be filled. Each row will be packed with a tractor tire or cultipacker after filling unless rhizomes are planted in soft mud. The area will be leveled and smoothed following planting and packing. Rows should be approximately 40 inches apart. They will be prevented from drying at all times during digging, packaging, transporting, and planting.

Management

Fertilization with additional 50-50-0 will speed establishment. Pool level should not be permitted over the plantings for any extended period during the first year. Livestock must be excluded at all times.

PLANTING AND MANAGEMENT GUIDE FOR VEGETATIVE WAVE PROTECTION OF EARTH DAM EMBANKMENTS

Name of Plant

Prairie cordgrass, *Spartina pectinata*

Description

Prairie cordgrass is a warm season perennial grass that spreads rapidly by stout rhizomes. It attains a mature height of 3-5 feet. The stiff, coarse stems reduce wave energy during the dormant stage as well as during the growing season. Seed production is variable between ecotypes, some produce abundant seed, others are sparse seed producers.

Rhizomatous spread is rapid after the plants are established. Most of the rhizomes are developed early in the spring and appear as new spring growth at distances up to 2-3 feet from the parent plant. The sharp tipped scaly rhizomes resist erosion as they tightly interlace the soil.

Adaptation

It is well adapted to all plant regions and a wide variation in soils. It is adapted to zone 1 and zone 2 of the embankment. Is a good erosion control plant for shorelines. It is primarily a fresh water plant but will tolerate brackish water or mild salinity conditions.

Establishment

A smooth, firm seedbed free of clods, stones, woody roots or other foreign matter should be prepared 3 to 4 inches deep. Fertilize with 50 pounds of nitrogen and 50 pounds of phosphorus (P_2O_5) per acre during seedbed preparation or at planting time. Planting should be done in late winter or early spring before the rhizomes break dormancy. Planting should be done in a furrow 4 inches deep with loose soil pushed or kicked over the rhizome within 10 minutes after it is dropped to prevent drying. The furrow will be filled to approximate ground level and packed with a cultipacker or tractor tire. The area should be smooth and level after the planting and packing operation is complete.

Rows should be about 40 inches apart with a minimum of three rows. Rhizomes will be cut in lengths of 8 to 12 inches and planted at the rate of 1 to 1-1/2 rhizomes per foot of row. Care should be taken to prevent drying of planting material during digging, packaging and planting operations.

Management

Fertilize with a minimum of 50 pounds of nitrogen per acre 2 or 3 years after establishment. Fence to protect from grazing.

PLANTING AND MANAGEMENT GUIDE FOR VEGETATIVE WAVE PROTECTION OF EARTH DAM EMBANKMENTS

Name of Plant

Switchgrass, *Panicum virgatum*

Description

Switchgrass is a warm season deciduous perennial native grass. The species is highly variable. Ecotypes have been studied that vary from short, upland forms to tall coarse stemmed lowland forms attaining a height of 8 to 10 feet. Two lowland varieties have been released that are adapted for this use, Kanlow and Pangburn. Upland varieties released mostly for forage production can be used in zone 2 where they are adapted.

Switchgrass spreads by short rhizomes to form large clumps or colonies. Abundant, tough fibrous roots effectively prevent erosion. The stiff stems of most varieties dissipate wave energy against the front slope but all varieties tend to fall over or break up early in the season following growth.

All varieties produce abundant seed that are used by birds. The vegetative cover affords excellent cover for loafing and nesting.

Adaptation

Switchgrasses are widely adapted from plant regions 1 through 8. It is adapted to many varying soils. The lowland types are adapted to zone 1 and lower portions of zone 2 while the upland types are adapted to zone 2. The lowland types tolerate wetness while the upland types are more drought resistant. They stand long periods of inundation after established. Lowland types exhibit some minor tolerance to salinity. Upland types are not tolerant to salinity.

Establishment

A smooth firm seedbed free of clods, stones, woody roots, or other foreign matter shall be prepared to a depth of 3 to 4 inches. Planting dates should conform with those for establishment of other warm season grass species. Fertilizer will be applied before or during the seedbed preparation. Fertilizer amount should be a minimum of 50 pounds of nitrogen and 50 pounds of phosphorus (P_2O_5). All seed shall be drilled across the slope parallel to the berm. A grass drill with depth control bands will be used. The grass seed shall not be planted deeper than 1/2 inch. The distance between rows shall not exceed 12 inches. The area seeded will be firmed with a cultipacker following seeding. Seeding rate should be 7.5 to 10 pounds pure live seed (PLS) per acre. Mulching is not required but in dryer areas it insures a stand. The pool level should not be permitted to inundate plantings for any prolonged period the first year.

Management

Fertilize no later than the first part of the growing season of the second year with 50 pounds of N per acre. Livestock must be excluded by fencing to insure adequate growth for wave action control.

PLANTING AND MANAGEMENT GUIDE FOR VEGETATIVE WAVE PROTECTION OF EARTH DAM EMBANKMENTS

Name of Plant

Reed canarygrass, *Phalaris arundinacea*

Description

Perennial with creeping rhizomes which spread slowly to form a dense sod. Growth is erect to three feet or more with wide, flat blades. Used by wildlife for grazing or cover for small animals.

Adaptation

It is widely adapted to all plant regions 1 through 10. In the southern portion of region 2 grass should be planted only if soil moisture is available continuously. It is adapted to many soils. Makes it best growth on moist fertile soils, well adapted to muck soils, wet bottoms, ditch banks, and water-courses. It makes excellent growth on upland soils that are frequently dry. Stays green over a long period. Is well adapted as a zone 1 plant for short fetch length and for zone 2. It needs a pH range from 5.5 to 7.0 for best growth. It is a heavy user of lime. In the warmer temperatures, it makes growth almost all year. It should not be used on small stream channels or on other streams where velocities are low.

Establishment

A smooth seedbed free of clods, stones, woody roots or other foreign matter shall be prepared to a depth of 3 to 4 inches. Fertilize with 50 pounds of nitrogen and 50 pounds of phosphorus (P_2O_5) during seedbed preparation or at planting time. Seeding should be done in the late summer or early fall and in the spring and up to July. All seed shall be drilled across the slope parallel to the berm. A grass drill equipped with depth control bands will be used. The grass should not be planted deeper than 1/2 inch and the distance between rows shall not exceed 12 inches. Seeding rate should be 6 to 8 pounds of PLS per acre. All areas will be smooth and level and cultipacked after seeding.

Management

Fertilize the year after establishment with a minimum of 50 pounds of nitrogen per acre. Fence to exclude all livestock.

PLANTING AND MANAGEMENT GUIDE FOR VEGETATIVE WAVE PROTECTION OF EARTH DAM EMBANKMENTS

Name of Plant

Sandbar willow, *Salix interior*

Description

Sandbar willow is a thicket forming rhizomatous perennial small tree or large single stemmed shrub. Rhizomatous spread is rapid and dense thickets develop in sandy soil. The trees commonly grow 12 to 16 feet tall. Abundant fibrous roots are formed along the rhizomes close to the surface of the soil.

The plants effectively protect the soil from erosion in areas that have a. reliable supply of moisture.

Adaptation

It is adapted to plant regions 1, 2, 3, 4, 5, and 6 where the water table is shallow or at the surface. It is best suited to the waterline area of zone 1 on the embankment and in sandy areas of the shoreline. It gives good protection to shoreline areas. It will not stand extended dry periods without severe stand damage. Insect and disease damage have been found in some ecotypes.

Establishment

No seedbed preparation is required for sandy soils. Area to be planted should be free of any competing plants. Plantings are made from cuttings 10-18 inches long. Cuttings are made from new growth that is from 1/2 to 3/4 inches in diameter. Plantings should be made in the spring. Approximately 1/3 of the cutting should be left exposed with at least two buds above ground. Care should be taken not to force the cuttings into the ground as the bark and cambium layer can be damaged. In soils such as sandy loam, planting should be made in furrows or with dibble and soil firmed around the cutting. Cuttings should be placed no more than three feet apart. Where more than one row is set, cuttings should be planted in a staggered pattern. Rows should be about 3 feet apart. It is not tolerant of even short dry periods during the establishment year. Planting can be made from rhizomes but seedings die very rapidly of subjected to any stress.

Management

It is a low maintenance requiring plant where adapted. Fertilizer applied the second year will enhance the establishment of plants. Penoxy herbicides should not be used in the area of these kinds of plantings.

PLANTING AND MANAGEMENT GUIDE FOR VEGETATIVE WAVE PROTECTION OF EARTH DAM EMBANKMENTS

Name of Plant

Giantreed, *Arundo donax*

Description

Giantreed is a tall, stiff-stemmed, wide-leafed introduce warm season perennial grass. It frequently attains a height of 10-12 feet. The showy plume-like heads form in the late summer and fall.

Giantreed is deciduous throughout most of the area where it has been planted for gully and streambank erosion control. In the south where temperatures do not drop below 20-25 degrees, it will sometimes initiate new spring growth from latent alternate buds formed at the nodes of the stems.

Spread and increase of giantreed is from short, large scaly rhizomes that originate on the sides of the woody root mass at the base of the plants. In old stands, the woody mass at the base develops into a large continuous almost solid barrier against erosion. The stiff stems dissipate wave energy against the face of the fill.

New vegetative growth of giantreed is readily used by grazing animals and the plants must be protected from grazing. Nutria eat the new shoots as they appear in early spring.

Adaptation

Giantreed is adapted to all plant regions 1 through 10. It has a wide adaptation to soils as long as they are well drained. It will not stand wetness or grow on low oxygen. It is adapted to zone 2 of the embankment. It will stand short periods of inundation if the water table does not remain high.

Establishment

A smooth, firm seedbed free of clods, stones, woody roots, or other foreign matter should be prepared 3 to 4 inches deep. All competition should be eliminated from the area to be planted. Planting stock should consist of dormant corms (woody portion of plant in root zone).

Dormant corms may be chopped with an axe, machette, or torn apart so that a minimum of 1 or 2 live buds occur on each piece. Corms can be planted in winter or very early spring before growth starts in furrows at the rate of 1-1/2 live buds per foot of row. Loose soil should cover the canes or corms to prevent drying. After filling the furrows, each row will be packed with a cultipacker. The area should be level after the planting and packing is complete. Care should be taken at all times to protect the planting material from drying. Care should be taken with cover to be sure buds are not damaged.

Giantreed (cont'd)

Management

Fencing for exclusion of livestock is required if livestock have access to the area. Fertilize plantings with 50-50-0 in the second and third year after planting to obtain maximum growth and vigor.

PLANTING AND MANAGEMENT GUIDE FOR VEGETATIVE WAVE PROTECTION OF EARTH DAM EMBANKMENTS

Name of Plant

Indigobush amorpha, *Amorpha fruticosa*

Description

Indigobush amorpha is a solitary leguminous shrub with lateral spreading roots and attractive bloom. The mature plants reach a height of 10-15 feet at maturity in favorable situations. It is a many branched, deciduous plant that does not readily root sprout. Basal buds freely develop into new upright or decumbent stems in some ecotypes. The genus *Amorpha* contains many woody and herbaceous species. The woody species only should be used for shorelines. Woody species within this group are variable to height and growth form. Some are open and upright, others are decumbent and open or compact.

The lateral spreading roots offer some protection against wave erosion but they do not freely develop fibrous roots so are not totally effective as an erosion control plant without supplemental support from plants with fibrous roots. The stiff, numerous stems effectively reduce wave action erosion to the front slopes during flood stages.

Abundant seed are produced on old wood. The resinous glandular seed have a distinctive odor. The attractive deep purple flowers are reportedly used by bees and the seed sparingly by bobwhite. Shore birds use indigobush for nesting sites.

Adaptation

It is widely adapted in plant regions 1, 2, 3, 5, and 6. It is adapted to zone 2 but primarily as a plant to be used in combination with a grass. It is a fresh water requiring plant.

Establishment

A smooth, firm seedbed should be prepared and be free of clods, stones, woody roots, or foreign material. No competitive vegetation should be present at planting time. The best planting dates are from late winter through early spring for bare root stock. Container grown stock can be planted at any time. Planting stock should range from 1/4 to 1/2 inch stem diameter. One year old nursery stock is satisfactory. When planting with spade, dibble, or mattock care should be taken to place the plant at or slighly deeper than it grew in the nursery. If mechanical tree planters are used, furrow or slit shall be deep enough to assure proper root placement. Packing wheel will be positioned to assure no air pockets and firm placement of the plant in the ground at or slightly deeper than it grew in the nursery. Container stock should be removed from the container with minimum damage to roots and placed in the bottom of the hole to assure no air pockets. No fertilizer is required for tree planting. Plants should be from 24 to 48 inches in the row (and staggered between rows).

Management

Fencing is not necessary for the protection of indigobush from grazing as livestock do not usually take it by choice. Fencing will be required for most of the fibrous rooted support plants used with indigobush. Penoxy herbicides should not be used on the area.